International Journal on Advanced Science Engineering Information Technology

Vol.5 (2015) No. 2
ISSN: 2088-5334

Optimization of PID Controller Parameters on Flow Rate Control System Using Multiple Effect Evaporator Particle Swarm Optimization

Bambang Dwi Argo, Yusuf Hendrawan, Dimas Firmanda Al Riza, Anung Nugroho Jaya Laksono [#]

[#] *Agricultural Engineering Department - Faculty of Agricultural Technology – Brawijaya University, Indonesia*
E-mail: anungnugroho99@gmail.com

***Abstract*— This study aims to improve the performance of Proportional+Integral+Differential (PID) control to reduce the speed of the steam flow rate and search optimal points in the evaporation process of Multiple Effect Evaporator (MEE). Optimization of PID control tuning parameters using Particle Swarm Optimization (PSO) by adding a weighting factor of inertia is expected to handle nonlinear systems with evaporator undershoot response characteristics that are difficult to treat and improve response of the system with large overshoot, and long rise time. The results showed PSO is able to provide improved performance tuning PID control system to improve system response in MEE control system with a rise time of 0.01 seconds, 3.35% overshoot, settling time of 6.10 seconds and able respond plant undershoot MEE of 28.11%.The results show that, PSO with inertia weight w provides additional tuning better than PID control by ZN method of max criteria over shoot, rise time and settling time of 5.38%, 3.05 seconds, 10.1 seconds, compared to tuning PID control method with PSO (3.35%, 0.01 seconds, 6.10 seconds).**

***Keywords*— PSO, PID, Evaporator, MEE, Inertia**

I. INTRODUCTION

Production systems in industrial processes are so complex and dynamic, so that the process often have undesirable conditions due to a lack of ability on the production process control system, such as the production process at the plant sap sugar. Lack of evaporation control performance or decreasing in water content in evaporator system resulting in product that is less than the maximum. This study aims to improve the performance of Proportional + Integral + Differential (PID) control to dampen the speed of the steam flow rate and do a search optimal points in the evaporation process and modeling the evaporator in mathematical. Optimization of PID control tuning parameters using Particle Swarm Optimization (PSO) by adding a weighting factor of inertia is expected to handle nonlinear systems with evaporator undershoot response characteristics that are difficult to treat and improve the system response with overshoot, rise time is quite long and large.This study is based on previous studies that have been tested are: the PSO tuning PID control can handle the dynamics of a system that have similar to the process that is optimal tuning of PID controller using adaptive hybrid particle swarm optimization algorithm [21], algorithm PSO to solve the problem of parameter estimation for nonlinear dynamic rational filters. For modeling the nonlinear rational filter, the filter of the unknown parameters are arranged in the form of a vector parameter called particles in PSO terminology [22], the problem of simultaneous and coordinated tuning parameters stabilizer and automatic voltage regulators (AVRs) advantage in multi-machine power system is considered. This problem is formulated as an optimization problem, which is solved by using particle swarm optimization technique (PSO). The purpose of a control parameter optimization problem solving nonlinear representing the allowable parameters of the system [6], a new design method for determining the optimal proportional-integral-derivative (PID) controller in AVR system using a tuning algorithm (PSO). Use intelligent system method to search for optimal efficiency, the approach of intelligent system such as to the PSO has excellent features, with easy implementation, stable convergence characteristics [16], optimal tuning of PID controller parameters on a dc motor based on advanced particle swarm optimization algorithm [1]. This research method is performed start from the design procedure and simulation tuning PID control based on PSO which includes two important phases, that are system modeling and design tuning PID control based on PSO. In the modeling system done by identifying process based on the data variable in the evaporator plant. The second stages is the PSO design as tuning PID control, the whole design of the research carried out by using the simulation software.

II. Material and Methods

A. Multi effect evaporators

Evaporator is a tool that servers to convert part or all of a solvent from a solution of liquid into vapor. Single-Effect Evaporator only through a single evaporation chamber and a space heater is given by the heat transfer surface area. Material (feed) and hot steam entering the same effect, the product came out well in the same effect [7]. To save the use of steam is usually used Multiple Effect Evaporator (MEE), in fig. 1 is a schematic process MEE, the workings of the setting of double effect the latent heat of the steam out of the products used for heating effect following its effects. Similarly, the effect of numbers starting with one heated by steam. It will have the highest pressure. Steam from the first effects will be used to heat the Securities second, which consequently will operate at lower pressures. It continues through the channel: pressure drop through the order so that steam will travel from one effect to the next effect [7].

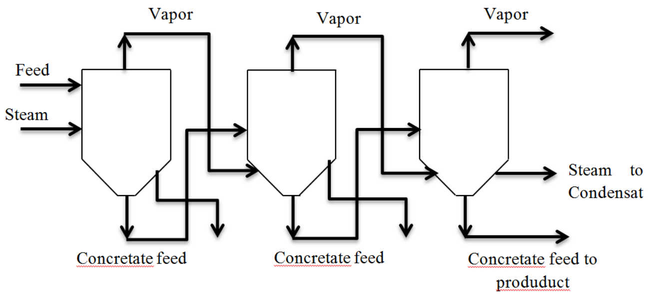

Fig.1. Triple Effect Evaporator

B. Mathematical Modeling of Multi Effect Evaporator

One way to resolve the dynamics of a production process by modeling a production system by modeling in mathematical methods, it is also useful to predict the production system work before production systems are used, one of the methods used numerical methods for predicting melting through the gap applied to the one-dimensional stefan problem using taylor series [3]. The systematics of this study contains the procedures that will be performed starting from the preparation stage began with literature study of the dynamics in the multi-effect of evaporator process and PSO algorithms as the tuning PID control until conclusion of the research. The method of this research can be explained into the following stages: searching input and output value of the physics equation, enter the mentioned value data toward mass and energy equilibrium, with the mass and energy equilibrium in a decrease in time as follows [17].

Feed mass and steam mass equilibrium

$$dM/dt = M_{in} - M_{out} - M_v \quad (1)$$

$$d(\rho_s v_s)/dt = \rho_s M_{sin}/v - \rho_s M_{sout}/v \quad (2)$$

Feed energy and steam energy equilibrium

$$dT/dt = M_f (T_{in} - T_s) + c_p \Delta T(T_{out} - T_s) \quad (3)$$

$$dH/dt = M_s/v_s * H_1 + U*A*\Delta T (T_s - T) - M_s/v_s * H_0 * V * Q \quad (4)$$

Enter the digits into the matrix space that is already in process simulation program, search criteria that must be controlled in some effect evaporator process, make a block diagram of a multiple effect evaporator process and PID control, create a set of PID based on PSO method, run the simulation and analysis chart (oscillation) and outcome data from the run control.

C. Input-Output Evaporator Model Identification

Identification procedures in the study had a complex process and based on three main factors, among others: the data, the structure of the model, and the selection criteria for identification.

D. State - Space

Completion of mathematic models of simpler ways to complete the transfer function is to create a state-space matrix [5], state-space as a theory to model the evaporator. In control engineering, the representation of the state space is a mathematical model of a physical system as a set of input and output variables associated with the first-order differential equations. The state space equation:

$$\dot{x}(t) = A(t)x(t) + B(t)u(t) \quad (5)$$

$$y(t) = C(t)x(t) + D(t)u(t) \quad (6)$$

A(t) : state matrix.
B(t) : input matrix.
C(t) : output matrix.
D(t) : direct transmission matrix.

Figure 2 block diagram of an image on a matrix representation of the state space

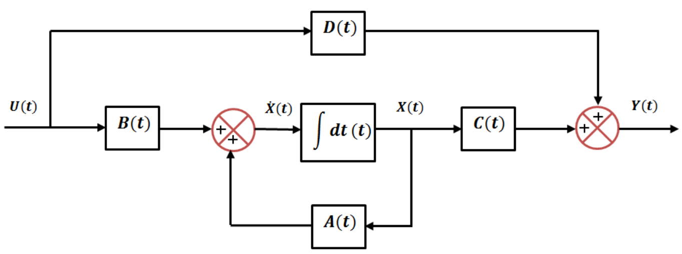

Fig. 2. Block diagram of the matrix State Space

E. Process Dynamics

The dynamics of a system of production process is very difficult to predict, although it is difficult lot of research on the analysis of the dynamics of the development process of a system, such as in research Dynamic response of split feed multi-effect evaporators using mathematical modelling and simulation [4]. The process in the evaporator involves the steam mass, feed mass, and energy, while the output in the form of mass vapor, viscous liquids and residue steam which into the condensate. Evaporator process must always produce steam and liquid, which is the result of the evaporation process. In this research, the reference for control the steam and feed masses, the steam mass into an evaluation component to determine the optimum viscosity in the evaporation process produces.

F. Evaporator System Model Identification

The identification of a production process is necessary because the results of the analysis of identification will be modeled in the form of empirical or analytical, like his thing in the process of evaporation in the evaporator system. The research shows the need for identification of the evaporator neural networks for nonlinear dynamic system modelling and identification [20]. The evaporator plant modeling using the identification method of physics equations derived from the mathematical model developed by Geankoplis [7] and put into the state-space matrix to assist the completion of the process dynamics equations in the evaporator plant, so the plant will represent the real conditions. In addition to using state-space modeling plant can be done use Laplace transformation method, but if too many variables are used in the research will complicate the transfer function. State-space in the process of system mathematical modeling is done with a data connection through the input-output variables evaporator.

G. PID tuning using PSO

Tuning optimization is a big influence on the performance of PID control, because the determination of the PID control is determined by the value of Kp, Ki, Kd. One method of tuning to determine the value of Kp, Ki, Kd is the method of PSO, the current tuning method with PSO has been much research done one robust PID controller tuning based on the constrained PSO [15]. PID control optimization process is done to get the right values in the PID control parameters, so the response generated controllers capable of handling the minimum conditions for the achievement of rapid setpoint and small overshoot. PSO algorithm is used to find the value of parameters optimization of PID control as show in Fig.3, because this method has the advantages of rapid convergence point in determining the desired minimum objective function, the search value of Kp, Ki, Kd, with PSO algorithm simulation program conducted on the parameters of the plant MEE.

Search framework parameters (Kp, Ki and Kd) in the self-tuning PID control using PSO is based on a performance index that is minimized through the objective function to meet the needs of the process.

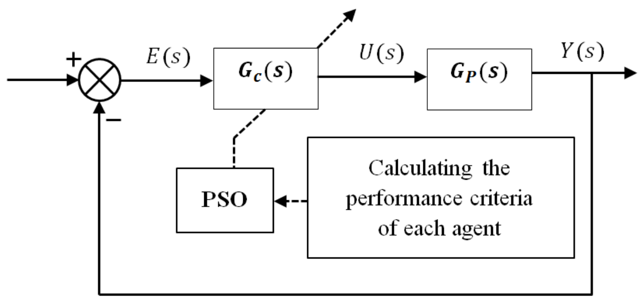

Fig.3. Structure Of PSO In Tuning PID Control [18]

H. Particle Swarm Optimization (PSO)

Optimization in the performance of a production process in the industry is necessary, one to streamline the performance of the means of production, process optimization are urgently needed as the study sizing optimization of standalone photovoltaic system for residential lighting [19]. Optimization using intelligent system has been successfully implement in some control systems [8] – [14]. Basic PSO technique is introduced by Kennedy and Elberhart in 1995, inspired by the social behavior of a flock of birds or fish. In the PSO, each solution is a point where a large number of particles moving in each dimension space. Birds (particles) will find their food through their own efforts and social cooperation with other birds in the vicinity. Process Flow PSO:

1. Generation of initial population random.
2. Evaluate the fitness function.
3. Compare the value of the fitness evaluation with p-best. If the value is now better than p-best, then set p-best value equal to the present value. And pbest-i, m (t) is equal to the value of the current position on the dimension m.
4. Identification of other particles that have p-best, if the value is greater than g-best p-best, then set equal to the pbest g-best.
5. Update the value of the speed and position of a particle.
6. Repeat step 2 until the criteria are matched (have optimal fitness value or the number of iterations has been reached).

Figure 4 show an illustration particles have velocity and position components that move random towards the best solution.

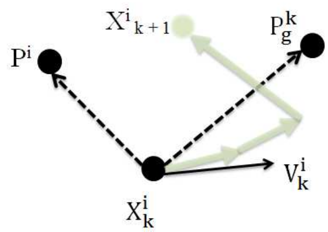

Fig. 4. The Concept Of Finding The Particle In Space Dimension By PSO

III. Results and Discussion

A. Plant Identification

The process mathematical model based on physics and subsequent equations in physics based on the time put into state space matrix using the system input-output data. The first step in modeling is the input-output data put into equilibrium equation, then put into a matrix data to simplify the deriving process becoming a matrix data before inclusion in the state space matrix formulation. From the state space method obtained process mathematical relation that form the transfer function of each input-output data. Figure 5 is a mathematical model dynamics between the output and input in the evaporator 1 and 2 with the steam mass in the evaporator as its set point.

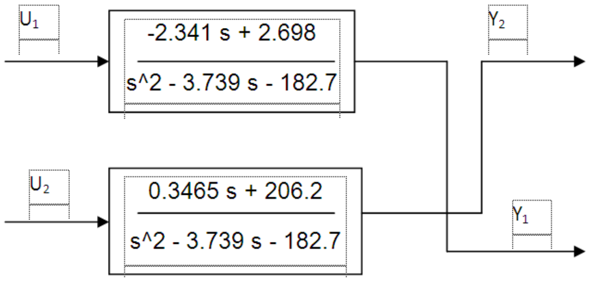

Fig.5. Mathematical Model Structure of Plant Multiple Effect Evaporator (MEE)

B. *Testing PSO System for PID Parameter Determination*

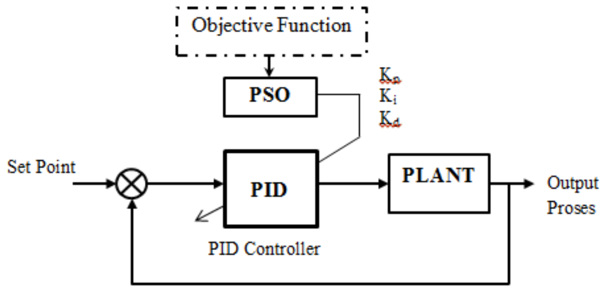

Fig. 6. Optimization Structure of PSO Tuning PID Control Parameters [2]

In determining the tuning parameters of PID control, the PSO must have the objective function to evaluate the function of the error through the iterative process of particles in the search space as shown in Fig. 7. PSO method is used as the optimization tuning, has some particles in the population, where each particle contains three members of the P, I and D, it means that every particle has a three-dimensional search space and the particles move in three-dimensional space. In search of a solution particle has a new position which is used as the basis for updating the particle positions are associated with the best previous position of the particle. General equation of the PID controller is:

$$U(t) = K_p \ x \, \mathrm{e(t)} + \frac{1}{T_i}\int e(t)dt + T_d \frac{de(t)}{dt} \qquad (8)$$

where : *Kp* = *Propotional Gain*
Ti = *Integral time*
Td = *Derivative time*

Error variable e(t) describes the difference between the setpoint with the actual output of the process. Large control signal issued by the PID control algorithm is multiplying error with Kp, Ki and Kd parameters. Three integral performance criteria in the frequency domain has advantages and disadvantages. The disadvantage of the Integral Absolute Error (IAE) and Integrated of Sequare Error (ISE) criterion is the response minimization process. Deriving Integral of Time Weight Square Eror (ITSE) formula in the analytic are complex and need to add time in its calculations. Performance criteria equation of IAE, ISE and ITSE are:

$$IAE = \int_0^\infty |r(t) - y(t)dt| = \int_0^\infty |e(t)|dt \qquad (9)$$

$$ISE = \int_0^\infty e^2(t)\,dt \qquad (10)$$

$$ITSE = \int_0^\infty t.e^2(t)\,dt \qquad (11)$$

Performance criteria include overshoot, rise time, settling time and steady state error.

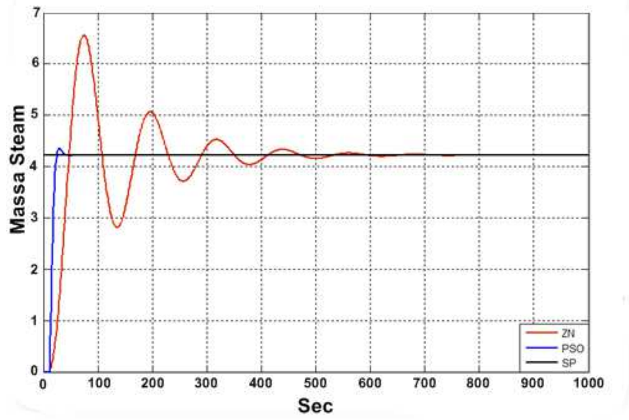

Fig. 7. Step Test at Setpoint 4.22 kg/s

Figure 7 above is a comparison the control response between tuning method based algorithm Ziegler-Nichols (ZN) with PSO in the MEE control process. From the results show the PSO is able to provide more optimal tuning options with max over shoot of 3.35% rise time 0.01 seconds and settling time 6.10 seconds compared to using the ZN max overs hoot 5.38%, rise time 3.05 seconds and settling time 10.1 seconds. PSO is able to improve the control response generated by lifting the fall response (undershoot) of 28.11% at the time of transient conditions.

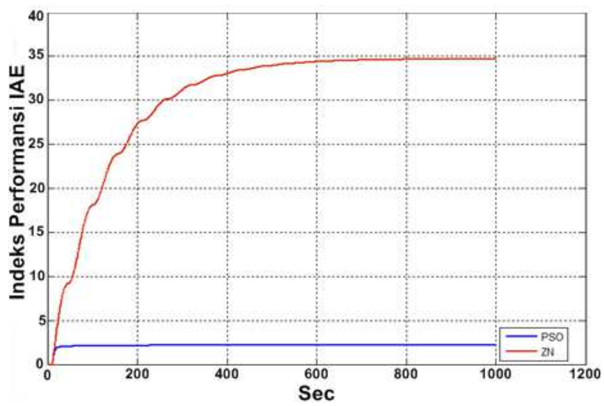

Fig. 8. Performance Index of IAE PSO and ZN

The comparison results of the control systems error performance test of ZN and PSO based on IAE, show PSO results more minimum error, it can be seen in Fig. 9, where ZN has the IAE index for 34.69, while PSO amounted to 2.53. This means that PSO is able to reduce the error generated during the control process runs. With the achievement of steady-state error value faster means PSO is able to achieve fast settling time in fulfilling the objective function is determined. In fig. 8 at the time of 7 seconds control error has not changed, which means the response has reached the setpoint.

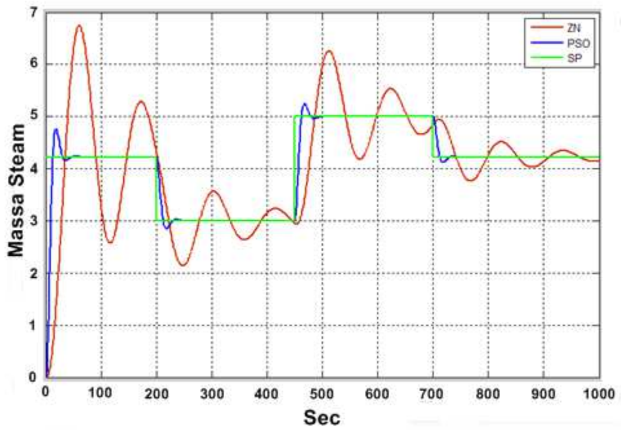

Fig. 9. Tracking Setpoint Test of PSO and ZN

Figure 9 is the tracking setpoint test at different levels of state control with PID control parameters are determined by PSO and ZN. From the results indicate that the parameters obtained through the optimization of PSO is able to provide a more optimal tuning options, so to improve the system response to meet its expected targets by settling time, rise time faster.

C. PSO on Inertia Test Weight (w) different

PSO performance is strongly influenced by inertia weight to reduce the speed of the particles in the update position, because the minimum value of the objective function is sought often overlooked. Figure 10 is the result of the PID controller system response with the Kp, Ki and Kd tuning based on a PSO algorithm with inertia weight w is different. From the results showed different controlling responses to a variety of PSO weights is used, where the fastest settling time is achieved when the PSO weight w = 0.80 with a more refined system response and there is nothing osilatif at the time of transient towards the setpoint.

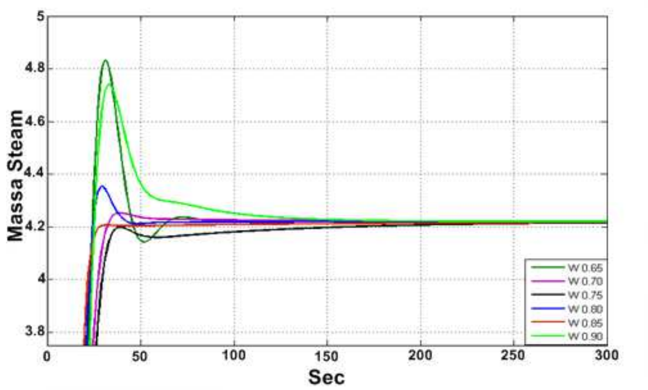

Fig. 10. Step Test at Setpoint 4.22 kg/s steam mass at various inertia weight parameter of PSO different

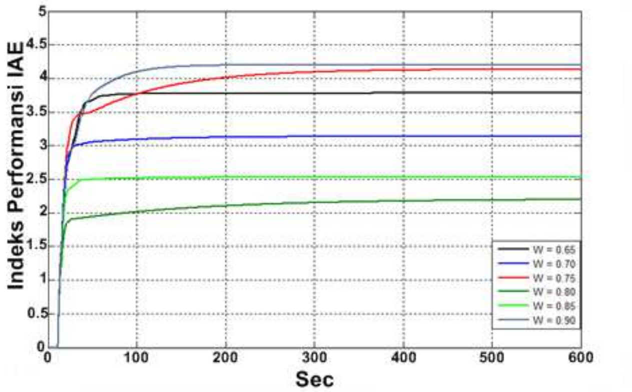

Fig. 11. Performance Index of IAE for the inertia weight w PSO different

Index performance control systems can be measured using MSE, IAE, ISE or ITAE. In this case, PSO as tuning PID control index performance parameters (Kp, Ki and Kd) were measured using the IAE. Figure 11 is measured using the IAE performance index to determine the control design PSO at different inertia weights. From the results suggest tuning the PSO with inertia weight w = 0.80 has the most minimum IAE index, the performance index compared with other inertia weight.

D. PSO Test on The Value of C1 and C2 are different

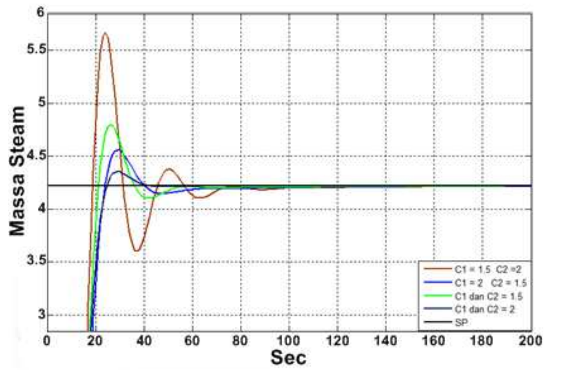

Fig. 12. Differences in C1 and C2 on PSO tuning with weights w = 0.85

Velocity of particles in the PSO algorithm in finding the search space is determined by the value of the C1 kognitive parameter and C2 parameter social. C1 kognitive parameter useful for maintaining relations of particles to other particles and C2 parameter social serves to maintain relations with all other particles in the population. From the simulation results by comparing the value of C1 and C2 are different, it affects the rate of particle velocity in fulfilling the objective function. Figure 12 shows a different controlling response on the step test setpoint 4.22 kg/s of steam mass. PSO with the value of C1 and C2 = 1.5 has a smoother response and non-oscillation at the time of transient conditions to the setpoint than the value of C1 and C2 are different, which generate oscillation when the condition of transient to the setpoint. Control response on the value of C1 = 1.5 and C2 = 2 has the greatest amplitude oscillations at the time of the transient to the setpoint.

E. PSO Test on the Number of Particles are Different

PSO performance also depends on the number of particles, where each particle can be a candidate solution in determining the point of optimization according to the evaluation function is expected. The particles number effect in search optimization point that the more number of particles, the longer search optimization point because each particle must go through an evaluation function to achieve desired criteria. Conversely, if the number of particles is too small then less likely to find the best position of the particle.

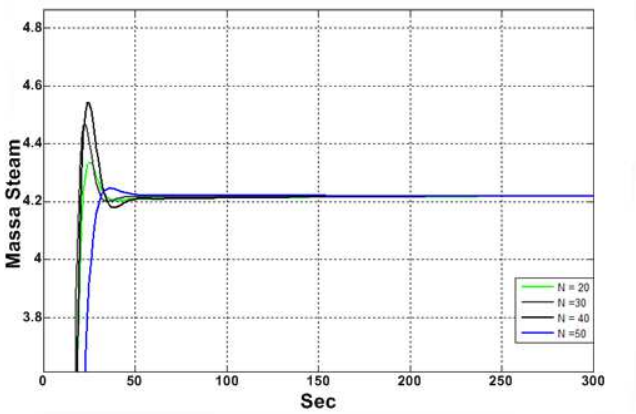

Fig. 13. Tuning Test of PID Controller with a Number of Different Particle

In Fig. 13 can be seen the effect of increasing the number of particles on the control performance that includes the maximum overshoot, rise time and settling time, the compensation awarded to an increase the number of particles that the longer search objective value due to each particle continuously iterate until the value reached a minimum of objective function that expected.

F. PSO Optimization Test based on Fitness Value by Total Population of 20

The number of iterations also affect the value of the optimization tuning PID control, the more number of iterations will get its optimum value. Figure 14 is the optimization of the test sample on the condition w 0.80 and iteration 50 times, the picture explained that the fitness value obtained at the time of 50th iteration has reached the optimum point with a value of approximately 2. The graphs which increasingly come down are have a good optimum value, because this research is looking for the most minimum value.

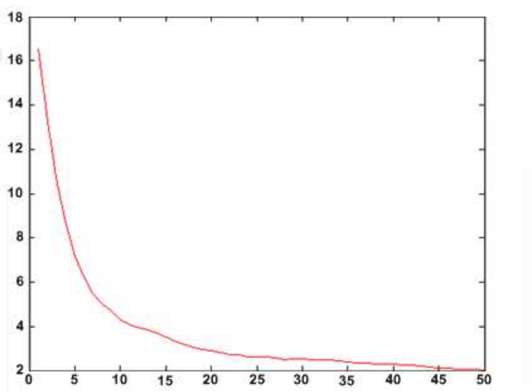

Fig. 14. Optimization Test on w 0.80 with 50 iterations

IV. Conclusions

The results of running the plant MEE with the tuning PID control based on the PSO method, its performance can be seen from the chart comparison with a fitness value with the criteria value w, c1, c2, are different. Factor of inertia weight (w) in the PSO is used to dampen the velocity of the particle to be more thorough in the search space the optimization to achieve a more optimal objective function. From the results of research conducted PSO is able to provide improved performance tuning PID control system to improve the control system response in MEE control system with a rise time of 0.01 seconds, overshoot of 3.35%, settling time of 6.10 seconds and was able to give a response undershoot plant MEE of 28.11%. From the results of the application of the plant MEE, PSO with inertia weight w able to provide better tuning than PID control parameters based on the ZN method. The response given by the ZN method of max overshoot criteria, rise time and settling time of 5.38%, 3.05 seconds, 10.1 seconds, from the results of tuning PID control method with PSO better with the results of the criteria overshoot, rise time, settling time, 3.35 %, 0.01 seconds, 6.10 seconds.

References

[1] A. Jalilvand, A. Kimiyaghalam, A. Ashouri, H. Kord. 2007. Optimal Tuning Of PID Controller Parameters On A Dc Motor Based On Advanced Particle Swarm Optimization Algorithm. Technical and Physical Problems of Engineering. Vol. 3: 10 – 17.

[2] Allaoua. B, Gasbaoui. B, Mebarki. B. 2009. Setting Up PID DC Motor Speed Control Alteration Parameters Using Particle Swarm Optimization Strategy. Leonardo Electronic Journal of Practices and Technologies ISSN: 1583-1078.

[3] B. Irawan, ING. Wardana, S. Wahyudi, B. Dwi Argo. 2013. Numerical Methods for Predicting Melting through the Gap Applied to the One-Dimensional Stefan Problem Using Taylor Series. Applied Mathematical Sciences, Vol. 7, 2013, no. 91, 4509 – 4519.

[4] D. Kumar, V. Kumar, V. P. Singh. 2012. Dynamic Response Of Split Feed Multi-Effect Evaporators Using Mathematical Modelling And Simulation. International Conference on Fluid Dynamics and Thermodynamics Technologies. Vol. 33.

[5] Derek. 2002. State-Space Representation of LTI Systems. Analysis and Design of Feedback Control Systems. Vol, 1 No. 2.

[6] El-Zonkoly, A.M. 2006. Optimal Tuning Of Power Systems Stabilizers And AVR Gains Using Particle Swarm Optimization. Expert Systems with Applications 31: 551–557.

[7] Geankoplis, C. J. 1993. Transport Processes and Unit Operations : third edition. Prentice-Hall,Inc.

[8] Hendrawan, Y. and Murase, H., 2009a. Precision Irrigation for Sunagoke Moss Production using Intelligent Image Analysis. Environment Control in Biology, 47(1), 21-36.

[9] Hendrawan, Y. and Murase, H., 2010a. Neural-Genetic Algorithm as Feature Selection Technique for Determining Sunagoke Moss Water Content. Engineering in Agriculture, Environment and Food, 3(1): 25-31.

[10] Hendrawan, Y. and Murase, H., 2011a. Non-Destructive Sensing for Determining Sunagoke Moss Water Content – Bio-inspired Approaches. Agricultural Engineering International: CIGR Journal, Manuscript No. 1564, Vol. 13, No. 1.

[11] Hendrawan, Y. and Murase, H., 2011b. Neural-Discrete Hungry Roach Infestation Optimization to Select Informative Textural Featuresfor Determining Water Content of Cultured Sunagoke Moss. Environment Control in Biology, 49(1):1-21.

[12] Hendrawan, Y. and Murase, H., 2011c. Bio-inspired Feature Selection to Select Informative Image Features for Determining Water Content of Cultured Sunagoke Moss. Expert Systems with Applications, 38(11): 14321-14335.

[13] Hendrawan, Y and Murase, H. 2011d. Neural-Intelligent Water Drops Algorithm to Select Relevant Textural Features for Developing Micro Precision Irrigation System Using Machine Vision. Computers and Electronics in Agriculture, 77(2): 214-228.

[14] Hendrawan, Y. and Murase, H., 2011e. Determining an ANN Pre-Treatment Algorithm to Predict Water Content of Moss using RGB Intensities. Engineering in Agriculture, Environment and Food, 4(4): 95-105.

[15] Kim, T.H, I. Maruta, T. Sugie. 2007. Robust PID Controller Tuning Based On The Constrained Particle Swarm Optimization Department Of Systems Science. Science Direct. Vol. 44: 1104 – 1110.

[16] Lee, Z. G. 2004. A Particle Swarm Optimization Approach for Optimum Design of PID Controller in AVR System. IEEE Transactions On Energy Conversion, Vol. 19, No. 2.

[17] M. Karimi, Jahanmiri. 2006. Nonlinear Modeling and Cascade Control Design for Multi Effect Falling Film Evaporators. Chemical and Petroleum Engineering Departement, Engineering, School, Shiraz, Iran.

[18] Pillay, N. 2008. A Particle Swarm Optimization Approach For Tuning Of SISO PID Control Loops. Durban University Of Technology Department Of Electronic Engineering.

[19] R Al, D. Firmanda. 2011. Sizing Optimization Of Standalone Photovoltaic System For Residential Lighting. University Technology Petronas.

[20] S. Chen, S. A. Billings. 1992. Neural Networks For Nonlinear Dynamic System Modelling And Identification. International Journal of Control Vol. 56: 2, 319 – 346.

[21] S. Morkos, H. Kamal. 2012. Optimal Tuning of PID Controller using Adaptive Hybrid Particle Swarm Optimization Algorithm. Communications & Control. Vol. VII: 101-114.

[22] Yih, L.L, Wei, D.C, Jer, G.H. 2008. A particle swarm optimization approach to nonlinear rational filter modeling. Expert Systems with Applications 34: 1194–1199.